3D scanning as a tool to measure growth rates of live coral microfragments used for coral reef restoration

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FlexScan3D Settings and Additional Steps

3.2.1 Preparation

We followed standard operating procedure as outlined in the FlexScan3D User Manual to calibrate and load the scanner and its software (Fig. S1A). During this stage, we adjusted scan settings to best capture the coral fragments and optimize time. Scan settings included the following: Standard clean-up of the 3D mesh function, a Smoothing value of 1, a maximum Mesh Density value, and the Number of Scans set to 12, with corals scanned by rotating every 30° around the central axis (Table S1).

3.2.2 Adjusting Exposure

Exposure is adjusted manually to ensure good scan quality. The High Dynamic Range (HDR) setting should be enabled when adjusting the exposure for live coral scans, as this setting enables the camera to use dual exposure to pick up contrasting reflective surfaces (i.e., the live coral and its plug within the custom stand). Once the coral is placed, the high and low exposure bars must be manually adjusted accordingly: the low exposure bar must be adjusted until the coral image becomes blue and the plug becomes grey, and the high exposure bar requires that the coral becomes grey in the scan image and the coral plug becomes red (Fig. S1B). These color combinations are necessary for the scanner to detect both the coral and its plug, which can be highly contrasting in color. For the scanner LED technology, the red coloration indicates that exposure is too high to be detected, while blue indicates that exposure is too low to be detected. Regardless of the species of coral and the fragment being assessed, exposure setting must be manually adjusted for each individual coral to ensure detection by the 3D scanner.

3.2.3 Scanning

We scanned the corals without the Automatic Alignment function enabled on the FlexScan3D software to minimize the time it takes for the software to process the scans, thereby supporting high-throughput processing. We set the number of scans to 18 to compare the accuracy of 12 versus 18 scans, but differences in calculated SA measurements were nominal (i.e., within 1-2% precision), thus we chose the final number of scans to be 12 to minimize air-exposure and processing times. After the scans are captured, the software begins “processing”. Once this dialogue box appears, the coral can be returned to its tank. After processing is completed, the scans should appear on the screen as unaligned meshes.

3.2.4 Alignment & Finalizing

We first aligned the captured scans using the Mesh Geometry function. This uses the geometry (shape) of the scanned object to align scans. Next, any scans that remained out of proper alignment, we manually aligned using the 3D widget to rotate scans into position (Fig. S1C). We then ran the Fine Alignment function to ensure all scans were accurately aligned. The aligned meshes could then be finalized into a single 3D mesh by using the Smooth Merge function (Fig. S1D).

During the finalizing process, there are two options for merging the selected scans. Precise Merge is the default setting and only makes minor adjustments during the merging step. Smooth Merge outputs a smoothed average mesh of the available scan data, and essentially makes more assumptions about gap filling in the scan data. We used the Smooth Merge function and its default settings, as it resulted in a more complete mesh and eliminated the need for hole-filling while still producing a visibly accurate model.

3.2.5 Mesh Editing

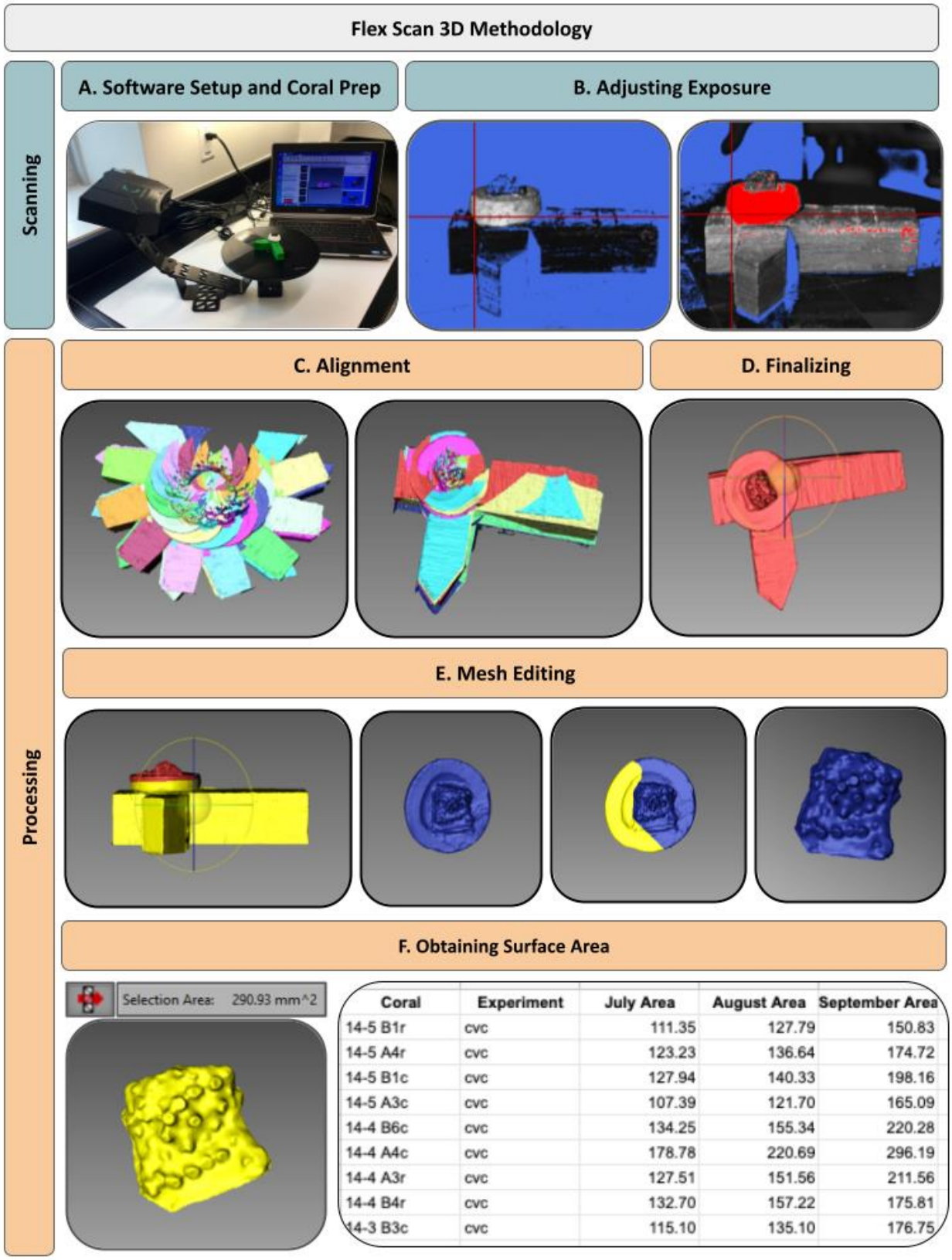
To obtain an accurate surface area (and thus accurately assess growth rates of coral microfragments), we edited the 3D meshes to remove all non-coral structures including the stand (Fig. S2) and the plug. We did this by manually highlighting sub-selections of the mesh with the cursor, and then deleting these sub-selections until only the coral microfragment remained (Fig. S1E). When completing this step, it is important to distinguish the coral tissue border from the plug and other fouling organisms. For certain corals or on heavily fouled plugs, it may become necessary to reference a photograph of the coral to determine the true tissue boundary. While the Hole-filling tool was not required for the *A. palmata* fragments herein, this tool may be needed when scanning other, more rugose coral species to ensure complete 3D meshes. Because hole-filling has the potential to introduce subject bias as well as inconsistency between corals, it is better to obtain complete, high quality scans to build a complete mesh rather than to rely on hole-filling. Hole-filling can be avoided by properly adjusting exposure prior to scanning and utilizing Smooth Merge when finalizing the mesh.

3.2.6 Obtaining Surface Area

After editing the 3D mesh to solely encapsulate the microfragment, we measured surface area by highlighting the entire remaining coral fragment, which prompts the FlexScan3D software to automatically display SA in mm^2 near the corner of the display. For this step, as well as editing the mesh, it is important to have the Select Through function enabled to make a selection all the way through the model and allow the user to highlight the entire tissue surface (Fig. S1F). The values obtained were then manually exported into a spreadsheet for data collection.

Supplementary Materials

Figures



Coral	Experiment	July Area	August Area	September Area
14-5 B1r	cvc	111.35	127.79	150.83
14-5 A4r	cvc	123.23	136.64	174.72
14-5 B1c	cvc	127.94	140.33	198.16
14-5 A3c	cvc	107.39	121.70	165.09
14-4 B6c	cvc	134.25	155.34	220.28
14-4 A4c	cvc	178.78	220.69	296.19
14-4 A3r	cvc	127.51	151.56	211.56
14-4 B4r	cvc	132.70	157.22	175.81
14-3 B3c	cvc	115.10	135.10	176.75

Figure S1. FlexScan3D Methodology Workflow. The scanning phase includes: **(A)** setting up and calibrating the camera, rotary table, and software, preparing and placing the coral; **(B)** using the High Dynamic Range (HDR) function to adjust both low and high exposure settings. The processing phase includes: **(C)** alignment, where the output includes 12 scans in different orientations denoted by unique colors, **(D)** finalizing, where the individual scans are merged, **(E)** mesh editing, where the target of interest (i.e., coral) is extracted from the 3D model, and **(F)** surface area quantification, where the target value is extracted from the coral model and manually exported to a datasheet.

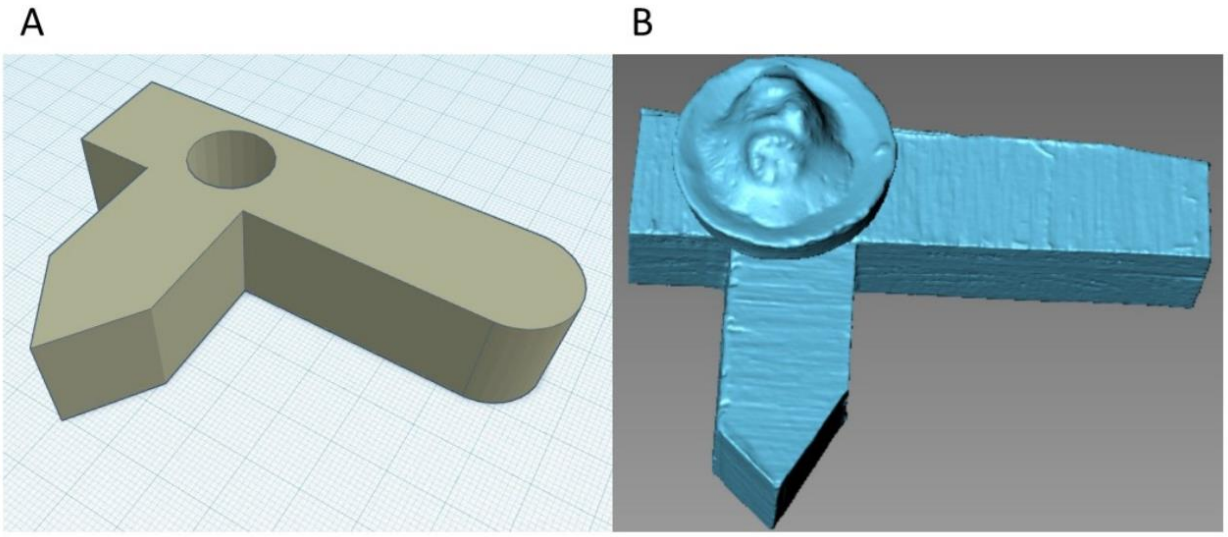


Figure S2. Custom-designed stand for coral fragments mounted on circular plugs. The stand has unique geometry on each side **(A)** for more effective scanning and a mounting spot **(B)** to securely hold the plug during scanning.

Tables

Software Stage		Setting
Scanning	Generate	Mesh
	Alignment	None
	Clean Up	Standard
	Smoothing	1
	Mesh Density	Maximum
	Number of Scans	12
	After Scan	None
	HDR	Selected
	High Exposure	Adjust bar until plug is bright red
	Low Exposure	Adjust bar until plug is grey
Finalizing	Merging Type	Smooth Merge
	Resolution	Low
	Smooth	Low
	Decimate	Deselected
	Hole Filling	Maximum
	Colour Processing	None

Table S1. Specific settings used in this study for obtaining scans using HDI Compact scanner and FlexScan3D software.